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MECHANICAL PROPERTIES OF REDWOOD.

BY

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MECHANICAL PROPERTIES OF REDWOOD.

THE STUDY.

This circular presents the results of a series of tests made to determine the mechanical properties of redwood.[1] They were made at laboratories of the Forest Service conducted in cooperation with the University of California, at Berkeley, and with the University of Washington, at Seattle.

The stringers and joists used in the tests were furnished without cost by the California Redwood Association. The material was selected at mills in Mendocino and Humboldt Counties, California, by representatives of the Forest Service. Care was taken to include timber which was representative of the range of quality found in market material.

THE REDWOOD OF COMMERCE.

DISTRIBUTION.

Redwood (*Sequoia sempervirens*) grows on the California coast in a strip extending inland from 10 to 30 miles and extending from the northern border of the State southward to a little below Santa Barbara. Redwood may be confused with the bigtree (*Sequoia washingtoniana*), noted for its size and age, but these "big trees" are no longer used for lumber, except in cases where they are blown down.

APPEARANCE AND CHARACTERISTICS OF THE WOOD.

The heartwood varies in color from a light cherry to a dark mahogany. The narrow band of sapwood is almost white. The wood is generally straight-grained and is comparatively light and soft, though individual pieces may be very hard and heavy and have an irregular grain. The number of annual rings in cross section of the material tested varied from 10 to 50 in an inch. The bark is reddish-brown in color and very fibrous.

USES.

Redwood is used for all kinds of construction and finishing purposes, for ties, shingles, paving blocks, telephone and telegraph poles, and tank and pipe staves. In Australia and on the Pacific

[1] Forest Service Bulletin 38, The Redwood, includes a study of the tree, of the brown-rot disease of the redwood, and of its insect enemies.

coast it is extensively used in the manufacture of sash and doors. Redwood ties equipped with tie plates laid in the valley between San Francisco and Los Angeles have given from 10 to 12 years' service. The adoption of a larger tie plate is expected to prolong the period of service, since from 80 to 85 per cent of the removals were due to mechanical wear. These ties were all split from logs a considerable distance below the limbs. Sawed ties and ties cut from limbs are considered less desirable. Immunity from decay and the ravages of white ants makes redwood desirable for tunnel timbers, foundation work, mudsills, curbing, fluming, paving blocks, fence posts, and telephone and telegraph poles. Redwood resists fire well, and even when ignited burns very slowly. It checks but little when exposed to the sun, and is practically free from resin. These properties make it especially suitable for use in buildings.

MATERIAL FOR THE TESTS.

The test material was divided into two classes.

The first class included stringers and joists which contain defects such as knots and checks present in timber purchased on the market. The stringers were of three sizes—8 by 16 inches by 16 feet, 6 by 12 inches by 16 feet, and 7 by 9 inches by 16 feet. The joists were of four sizes—3 by 14 inches by 16 feet, 2 by 12 inches by 16 feet, 2 by 10 inches by 16 feet, and 2 by 8 inches by 16 feet. There were 10 of each size. The purpose of the tests on this material was to secure strength values for use in design; to find out whether there were differences in strength values of timber from different localities, and to determine the influence of seasoning and defects on the strength of commercial-sized timbers.

The second class was made up of small, clear, straight-grained specimens cut from the uninjured portions of the tested stringers and joists, and these in turn were tested to study the effects on their strength of the rate of growth of the proportion of summerwood and of the weight. For such studies only perfect, clear material can be used.

METHODS OF TESTS.[1]

Four kinds of tests were made, to show strength in bending, in compression parallel to grain, in compression perpendicular to grain, and in resistance to shearing.

BENDING TESTS.

In the bending tests, the specimens were supported near the ends and the load applied either at the center or at two points each one-third the length of the span from the end supports. This latter

[1] For a more complete description of the methods of test employed by the Forest Service see Bulletin 108, Tests of Structural Timbers, by McGarvey Cline and A. L. Heim.

method is termed third-point loading. Center loading was used in the tests of small, clear specimens, 2 by 2 by 30 inches; third-point loading, which more nearly corresponds to the conditions to which a beam is subjected in structural work, was used in testing the stringers and joists. In the tests of joists a special support was used at the ends and third-points to keep the joist from tipping over. The tests were made with a universal testing machine and the load was applied gradually and continuously until the pieces failed. The amount of bending or deflection at the center of the piece was noted at regular increments of load. Four factors were calculated from the data derived from each bending test, all in terms of pounds per square inch. These were:

Fiber stress at elastic limit, which represents the greatest stress that a beam can sustain under a load from which it will recover without permanent deflection.

Modulus of rupture, which represents the greatest computed stress in a beam which has been loaded to the breaking point.

Modulus of elasticity, which is a factor computed from the relation between the load and deflection within the elastic limit and which represents the stiffness of the piece of wood under test.

Horizontal shear, which represents the force that tends to split the beam under test into two halves along the neutral plane, for example the plane between the upper and lower halves when the beam is horizontal.

COMPRESSION PARALLEL TO THE GRAIN.

In the tests for compression parallel to the grain two sizes of specimens were used, 6-inch by 6-inch by 24-inch pieces cut from the stringers, and 2 by 2 by 8 inch pieces cut from all small bending-test specimens. These pieces were set upright on the weighing platform of the testing machine and crushed endwise. Observations of load and deflection were recorded as in the bending tests. From the data recorded the following factors were calculated in terms of pounds per square inch: Crushing strength at elastic limit, crushing strength at maximum load, and modulus of elasticity.

TABLE 1.—*Average values for green and air-seasoned material in each size tested, with ratios of strength values of air-seasoned material to those for green material.*

Cross section.	Bending.								Compression parallel to grain.						Compression perpendicular to grain.					Shearing.		
	Span.	Number of tests.	Moisture.	Rings per inch.	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.	Calculated shear.	Size of specimen.	Number of tests.	Moisture.	Crushing strength at elastic limit.	Modulus of elasticity.	Crushing strength at maximum load.	Stress area.	Height.	Number of tests.	Moisture.	Crushing strength at elastic limit.	Number of tests.	Moisture.	Shearing strength.
Inches.	*In.*		*Per cent.*	*No.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*Lbs. per sq. in.*	*Inches.*		*Per cent.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*Lbs. per sq. in.*	*Inches.*	*In.*		*Per cent.*	*Lbs. per sq. in.*		*Per cent.*	*Lbs. per sq. in.*
GREEN MATERIAL.																						
8 by 16	180	14	86.5	19.9	3,734	4,492	1,016	300	6 by 6	36	83.4	3,146	1,240	3,865	6 by 8	16	13	86.7	473	140	82.5	740
6 by 12	180	14	87.3	17.8	3,787	4,451	1,068	224	2 by 2	145	75.8	3,476	1,153	3,954	6 by 6	12	14	83.0	424	......	......	......
7 by 9	180	14	79.8	16.7	4,412	5,279	1,256	199	......	......	......	......	......	......	6 by 7	9	13	74.7	477	......	......	......
3 by 14	180	13	86.1	23.7	3,506	4,364	947	255	......	......	......	......	......	......	6 by 3	14	13	75.6	411	......	......	......
2 by 12	180	12	70.9	18.6	3,100	3,753	1,052	187	......	......	......	......	......	......	6 by 2	12	12	66.5	430	......	......	......
2 by 10	180	13	55.8	20.0	3,285	4,079	1,107	169	......	......	......	......	......	......	6 by 2	10	11	55.0	423	......	......	......
2 by 8	180	13	63.8	21.5	2,989	4,063	1,141	134	......	......	......	......	......	......	6 by 2	8	12	56.7	396	......	......	......
2 by 2	28	157	75.5	19.1	4,750	6,980	1,061	248	......	......	......	......	......	......	2 by 2	2	186	75.5	569	......	......	......
AIR-SEASONED MATERIAL.																						
8 by 16	180	6	26.3	22.4	3,797	4,428	1,107	294	6 by 6	16	17.8	......	......	4,232	6 by 8	16	5	25.4	548	115	1.28	722
6 by 12	180	6	16.1	17.7	3,175	3,353	728	167	2 by 2	150	15.6	......	......	5,059	6 by 6	12	6	14.7	610	......	......	......
7 by 9	180	6	15.9	15.2	3,280	4,002	1,104	147	......	......	......	......	......	......	6 by 7	9	5	14.8	500	......	......	......
3 by 14	180	6	13.1	24.4	......	5,033	......	291	......	......	......	......	......	......	6 by 3	14	2	12.6	470	......	......	......
2 by 12	180	5	13.8	14.4	3,928	5,336	1,249	260	......	......	......	......	......	......	6 by 2	12	2	16.2	498	......	......	......
2 by 10	180	5	13.8	24.8	3,757	4,606	1,198	186	......	......	......	......	......	......	6 by 2	10	4	14.3	511	......	......	......
2 by 8	180	6	13.7	20.7	4,314	5,050	1,313	166	......	......	......	......	......	......	6 by 2	8	2	13.2	429	......	......	......
2 by 2	28	131	15.2	18.9	4,858	7,822	1,146	279	......	......	......	......	......	......	2 by 2	2	145	13.8	564	......	......	......
RATIO, AIR-SEASONED TO GREEN.																						
8 by 16	......	......	......	......	1.02	0.99	1.09	0.98	6 by 6	......	......	......	......	1.09	6 by 8	16	......	......	1.16	......	......	0.98
6 by 12	......	......	......	......	.84	.75	.68	.75	2 by 2	......	......	......	......	1.28	6 by 6	12	......	......	1.44	......	......	......
7 by 9	......	......	......	......	.74	.76	.88	.74	......	......	......	......	......	......	6 by 7	9	......	......	1.05	......	......	......
3 by 14	......	......	......	......	......	1.15	......	1.14	......	......	......	......	......	......	6 by 3	14	......	......	1.14	......	......	......
2 by 12	......	......	......	......	1.27	1.42	1.19	1.39	......	......	......	......	......	......	6 by 2	12	......	......	1.16	......	......	......
2 by 10	......	......	......	......	1.14	1.13	1.08	1.10	......	......	......	......	......	......	6 by 2	10	......	......	1.21	......	......	......
2 by 8	......	......	......	......	1.44	1.24	1.15	1.24	......	......	......	......	......	......	6 by 2	8	......	......	1.08	......	......	......
2 by 2	......	......	......	......	1.02	1.12	1.08	1.12	......	......	......	......	......	......	2 by 2	2	......	......	.99	......	......	......

COMPRESSION PERPENDICULAR TO THE GRAIN.

In the tests for compression perpendicular to grain the specimens consisted of one 24-inch section from each stringer and joist and one 2 by 2 by 8 inch section from each of the small bending specimens. Tests on the stringer and joist specimens were made by placing the piece on its narrow face, on the weighing platform of the testing machine, with the grain parallel to the platform. The load was applied to a steel plate 6 inches wide. The 2-inch-wide specimens were similarly tested, except that the steel plate through which the load was applied was only 2 inches across instead of 6 inches. Corresponding observations of load and deflection or crushing were taken, up to the elastic limit. From the data recorded, the crushing strength at elastic limit was calculated for each test in pounds per square inch.

SHEARING.

The shearing tests were made on small, clear blocks with a projecting lip 2 by 2 inches in section. The blocks were held firmly and the lip sheared off parallel to the grain. The load required to shear off the lip was computed in pounds per square inch for each test.

TABLE 2.—*Relative strength of material from Mendocino County (Shipment A) and Humboldt County (Shipment B), green material.*

Materials.	Number of tests.	Weight per cubic foot (oven-dry).	Moisture.	Rings per inch.	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.	Calculated horizontal shear.
		Pounds.	*Per cent.*	*Number.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*	*Lbs. per sq. in.*
8 by 16 inches—15-foot span:								
Shipment B	7	21.4	99.0	16.5	3,707	4,506	981	298
Shipment A	7	23.0	74.0	23.2	3,760	4,479	1,051	301
Ratio, Shipment B to Shipment A		93.1		71.2	98.6	100.5	93.2	99.1
6 by 12 inches—15-foot span:								
Shipment B	7	21.5	91.5	10.3	3,609	4,109	972	205
Shipment A	7	23.8	83.0	25.4	3,966	4,794	1,163	242
Ratio, Shipment B to Shipment A		90.4		40.6	91.0	85.7	83.5	84.7
7 by 9 inches—15-foot span:								
Shipment B	7	21.5	82.2	13.3	3,919	4,256	1,115	157
Shipment A	7	24.9	77.4	20.2	4,906	6,303	1,396	241
Ratio, Shipment B to Shipment A		86.4		65.8	79.8	67.5	79.9	65.2
3 by 14 inches—15-foot span:								
Shipment B	7	22.2	82.5	19.4	3,506	4,450	984	259
Shipment A	6	22.3	90.2	28.7	3,340	4,263	905	249
Ratio, Shipment B to Shipment A		99.6		67.7	104.9	104.3	108.7	104.0
2 by 12 inches—15-foot span:								
Shipment B	6	23.0	82.4	15.3	3,507	3,873	1,176	190
Shipment A	6	23.1	59.5	21.9	2,693	3,633	928	183
Ratio, Shipment B to Shipment A		99.6		69.9	130.2	106.6	126.7	103.8
2 by 10 inches—15-foot span:								
Shipment B	7	23.2	73.1	14.6	3,587	4,182	1.130	172
Shipment A	6	23.1	35.6	26.3	2,933	3,960	1,080	166
Ratio, Shipment B to Shipment A		100.3		55.5	122.4	105.7	104.6	103.5
2 by 8 inches—15-foot span:								
Shipment B	7	22.7	74.1	17.9	2,414	3,185	1.089	104
Shipment A	6	23.1	51.8	25.6	3,658	5,087	1,200	170
Ratio, Shipment B to Shipment A		98.4		70.0	66.1	62.7	90.8	61.2
2 by 2 inches—28-inch span:								
Shipment B	84	21.2	81.0	14.5	4,527	6.555	1,025	232
Shipment A	73	23.8	68.9	24.4	5,018	7.458	1,101	266
Ratio, Shipment B to Shipment A		89.2		59.5	90.3	87.8	93.1	87.2

TABLE 3.—*Results of individual tests on green stringers and joists.*

Size.	Reference No.	Moisture.	Dry weight per cubic foot.	Rings per inch.	Proportion of summerwood.	Proportion of sapwood.	Cross-section classification.	Modulus of rupture (per square inch).	Fiber stress at elastic limit (per square inch).	Modulus of elasticity (per square inch).	Horizontal shear (per square inch).	Number of knots. Vol. 1. Less than 1½ inches.	Number of knots. Vol. 1. 1½ inches and over.	Number of knots. Vol. 2. Less than 1½ inches.	Number of knots. Vol. 2. 1½ inches and over.	Number of knots. Vol. 3. Less than 1½ inches.	Number of knots. Vol. 3. 1½ inches and over.	Other defects.	Manner of failure.[1]	Apparent cause of failure.
Inches.		*P. cent.*	*Lbs.*	*No.*	*Per ct.*	*Per ct.*		*Lbs.*	*Lbs.*	*1,000 lbs.*	*Lbs.*									
8 by 16	1	89.9	22.4	29.4	44	0	1	6,610	4,900	1,188	446	....	....	1	1	9	1	....	C. T.	None.
	2	66.3	24.9	27.5	30	0	1	5,660	4,510	1,348	383	1	....	....	1	1	....	....	C. T.	None.
	3	116.1	20.8	20.3	36	0	3	5,180	4,600	1,010	348	1	....	4	5	14	11	....	C. T.	Large knot on upper face.
	4	52.3	22.2	21.5	31	0	1	5,170	3,900	1,203	339	....	....	12	2	2	9	....	C. T.	None.
	5	57.9	25.9	28.0	28	0	1	4,650	4,590	1,296	315	3	....	3	1	12	1	....	T.	Large corner knot 50 inches from center.
	6	157.7	19.8	16.5	35	0	1	4,620	4,110	967	307	1	....	....	....	1	....	....	C.T.	None.
	7	56.0	26.0	18.0	25	0	3	4,540	3,320	1,343	307	....	1	1	1	8	12	....	S.	None.
	8	62.2	23.1	17.0	38	0	3	4,440	3,420	1,265	297	....	....	3	3	5	7	....	S.	None.
	9	63.7	18.2	19.0	26	0	1	4,410	3,280	928	294	....	....	1	1	2	1	....	C. T.	None.
	10	167.4	21.2	8.5	45	0	1	4,140	3,080	688	272	....	....	....	....	10	....	....	T.	None.
	11	64.6	20.2	14.0	16	0	1	4,010	3,660	871	265	....	1	1	2	2	2	....	C. T.	Large knot on upper face.
	12	74.2	22.0	27.3	36	0	1	4,000	3,610	607	268	....	....	....	....	2	2	....	T.	None.
	13	121.0	23.5	8.5	31	0	1	3,530	3,410	861	229	....	2	....	1	6	6	....	T.	None.
	14	61.8	20.9	22.6	33	0	2	1,930	1,880	645	129	2	1	....	4	7	7	....	T.	Irregular grain caused by knot.
Average	....	86.5	22.2	19.9	32	....	....	4,492	3,734	1,016	300	....	....	....	....	....	....	....	....	
6 by 12	15	65.9	28.5	36.0	43	0	3	5,970	4,290	1,285	303	....	1	1	5	19	15	....	C. T. S.	None.
	16	143.2	22.5	17.3	34	0	1	5,850	5,130	1,345	294	....	....	....	....	....	....	....	C. T.	None.
	17	91.1	23.0	11.0	36	0	2	5,520	4,340	1,148	279	....	....	1	....	1	....	....	C. T.	None.
	18	64.0	24.5	10.0	23	0	2	5,460	4,890	1,283	278	1	1	1	1	5	2	....	C. T.	None.
	19	75.1	22.0	22.0	31	0	1	4,860	4,610	1,057	245	....	....	....	....	....	....	....	C. T.	None.
	20	214.8	20.3	8.9	28	0	1	4,820	4,210	1,131	236	....	....	....	....	2	....	....	C. T.	None.
	21	59.6	28.1	24.3	36	0	1	4,710	3,770	1,572	239	3	....	2	2	14	8	....	C. T.	None.
	22	69.8	21.5	39.7	27	0	1	4,580	3,710	1,128	232	....	....	....	2	6	2	....	T.	None—brash failure.
	23	96.9	22.8	7.5	20	0	1	4,300	3,550	566	215	....	....	....	....	4	....	....	T. S.	None.
	24	84.8	21.8	19.5	37	0	2	4,080	2,840	672	207	....	....	....	....	....	....	....	T.	None—brash failure.
	25	82.9	22.1	18.7	32	0	3	3,510	3,410	1,084	177	....	....	9	1	20	11	....	T. C.	None.
	26	60.0	21.0	16.0	14	0	1	2,999	2,650	746	148	....	....	....	....	3	15	....	T.	Wavy grain 15 inches from center.
	27	65.5	18.0	9.9	12	0	1	2,970	2,940	933	145	....	2	....	1	1	3	....	T.	Large knot 40 inches from center.
	28	48.0	20.7	9.0	14	0	4	2,700	2,680	998	135	1	1	9	3	24	17	....	T. S.	Large knot 40 inches from center.
Average	....	87.3	22.6	17.8	28	....	....	4,451	3,787	1,068	224	....	....	....	....	....	....	....	....	

7 by 9	29	48.2	30.6	24.8	41	0	1	9,760	6,750	2,222	407						2		C.T.S.	None.
	30	51.7	21.5	20.0	33	0	3	7,180	5,530	1,560	267	9		3	3	36	5		C.T.	None.
	31	94.3	28.3	20.3	36	7	1	6,920	5,710	1,432	260			2					C.T.	None.
	32	75.5	25.5	14.3	28	0	3	6,880	5,360	1,377	253			1	2	6	6		C.T.	None.
	33	57.1	22.3	28.0	14	0	1	6,100	4,820	1,306	226					2		Curl	C.T.	None.
	34	66.3	22.6	19.5	30	0	3	5,750	4,000	1,070	212	2		6	5	25	3		C.T.	Large knot on top face near center.
	35	128.3	25.6	27.8	39	0	1	4,900	4.320	1,354	186								C.T.	None.
	36	61.8	21.8	7.0	12	0	1	4,630	4,380	1,106	171	2		4		31	7		C.T.	None.
	37	216.9	19.8	8.0	15	0	1	4,300	4,000	1,075	156					3	1		C.T.	None.
	38	50.3	22.5	12.0	13	0	3	3,830	3,780	1,143	141	5	1	2	4	30	16		T.	Large knot on bottom face 53 inches from center.
	39	52.6	21.7	15.0	22	0	1	3,710	3,550	1,172	136					1	2		T.	Cross grain.
	40	67.1	21.0	16.0	18	0	1	3,710	3,400	714	136	1	2			3	2		T.	Large knot on bottom face 50 inches from center.
	41	69.3	21.1	7.0	13	0	1	3,510	3,500	1,290	132		1	2	2	3	6		T.	Cross grain.
	42	77.6	16.9	14.5	21	0	1	2,730	2,670	759	103		1			1	2		T.	Irregular grain.
Average		79.8	23.2	16.7	24			5,279	4,412	1,256	199									
3 by 14	43	64.5	26.0	22.8	8	0	1	6,410	4,560	1,383	373	1				13	7		C.T.	None.
	44	51.2	27.3	31.4	32	0	1	6,000	4,430	1,312	353			1	1	24	5	Shake	C.S.	None.
	45	58.8	23.5	32.8	14	0	1	5,730	3,950	1,258	339			2	1	1	3		C.T.	None.
	46	130.8	23.2	42.1	36	0	1	4,730	3,560	976	276			2	1	11	5		C.T.	Small knot on top face 20 inches from center.
	47	98.2	26.8	17.5	16	0	1	4,570	3,780	855	269					1			C.T.	None.
	48	70.4	19.9	15.5	10	0	2	4,180	3,630	994	239	1	2		1	5	6		C.T.	None.
	49	132.8	20.0	10.0	15	0	1	4,030	3,550	1,000	235			1	2	4	5		S.	None.
	50	63.2	17.6	29.5	8	0	1	4,000	2,860	697	231					2			C.T.	None.
	51	66.8	23.3	19.5	31	0	1	3,900	2,960	816	227			2		4	3		T.	None.
	52	139.2	21.5	38.1	37	0	1	3,890	3,610	982	228	1		4		73	3	Checks	S.	None.
	53	74.2	17.1	15.7	25	0	1	3,620	2,870	696	211					1	1		C.T.S.	None.
	54	79.3	21.1	25.5	35	0	1	3,440	2,610	646	200					1	1		C.T.	None.
	55	89.6	21.7	7.8	12	0	1	2,230	2,210	702	128					3	6		S.	None.
Average		86.1	22.2	23.7	21			4,364	3,506	947	255									
2 by 12	56	38.5	25.5	31.5	9	0	1	5,710	5,270	1,602	279					6			C.	None.
	57	54.8	23.0	15.0	19	0	1	4,010	3,250	1,196	203		1		2	14	12		C.T.	None.
	58	41.1	20.8	16.3	32	0	2	3,900	2,990	983	198			2	2	1	4		C.S.	Large knot on top face 15 inches from center.
	59	88.6	25.5	17.3	39	0	2	3,810	2,500	1,128	191	1		3					T.	None—brash failure.
	60	124.3	17.2	10.5	12	0	1	3,790	3,150	1,042	188					29			C.	None.
	61	47.6	22.1	31.6	27	0	3	3,790	2,920	891	190			2	3	12	7		C.T.	Large knot on top face 15 inches from center.
	62	90.2	18.8	11.1	19	0	2	3,770	2,420	1,109	189	5	1	3	3	1	1		C.T.	Large corner knot 22 inches from center.
	63	48.9	27.6	34.2	29	0	1	3,680	2,910	537	186					1			T.	None—brash failure.
	64	77.7	20.0	7.0	12	0	2	3,360	3,270	1,037	165		1		2	6	3		C.T.	None.
	65	145.9	30.5	7.0	32	0	2	3,190	3,040	839	152					3	4		T.	None—brash failure.

[1] Letters indicate sequence and kind of failure; C. indicates compression, T. tension, and S. horizontal shear.

TABLE 3.—*Results of individual tests on green stringers and joists*—Continued.

Size.	Reference No.	Moisture.	Dry weight per cubic foot.	Rings per inch.	Proportion of summer-wood.	Proportion of sapwood.	Cross-section classification.	Modulus of rupture (per square inch).	Fiber stress at elastic limit (per square inch).	Modulus of elasticity (per square inch).	Horizontal shear (per square inch).	Number of knots. Vol. 1. Less than 1½ inches.	Number of knots. Vol. 1. 1½ inches and over.	Number of knots. Vol. 2. Less than 1½ inches.	Number of knots. Vol. 2. 1½ inches and over.	Number of knots. Vol. 3. Less than 1½ inches.	Number of knots. Vol. 3. 1½ inches and over.	Other defects.	Manner of failure.[1]	Apparent cause of failure.
Inches.		*P. cent.*	*Lbs.*	*No.*	*Per ct.*	*Per ct.*		*Lbs.*	*Lbs.*	*1,000 lbs.*	*Lbs.*									
2 by 12	66	52.9	22.1	20.8	14	0	1	3,180	3,060	1,337	156	1	2	6	1	9	9		T	Large corner knot 30 inches from center.
	67	40.7	23.7	20.7	30	0	1	2,850	2,420	919	145	1	4	1	3	13	15		T	Large corner knot 21 inches from center.
Average		70.9	23.1	18.6	23			3,753	3,100	1,052	187									
2 by 10	68	39.1	25.6	22.5	14	0	1	6,510	5,170	1,584	273					2			C. T	None.
	69	81.5	24.6	22.0	10	0	2	5,200	4,390	1,304	212					20			C. T	None.
	70	54.3	27.6	32.3	32	0	2	5,190	4,090	1,456	217			1	2	3	1		C. T	Large knot on top face 28 inches from center.
	71	90.8	25.1	10.0	15	0	2	4,520	3,860	982	189			2		6	2		C. T	None.
	72	69.0	22.3	15.0	14	0	1	4,350	3,690	1,333	177	1				6	1		C. T	None.
	73	31.2	26.5	28.8	36	0	2	4,290	3,020	571	178					53			C	None.
	74	38.6	20.7	26.5	37	0	1	4,080	3,070	1,019	174					8	8		S	Checks.
	75	33.4	17.8	33.8	31	0	1	3,460	2,220	671	145					34		Shake	C	None.
	76	27.6	21.8	18.3	30	0	2	3,380	3,260	1,121	140			6	2	9	4		S	Checks.
	77	28.8	24.2	18.0	21	0	1	3,360	1,940	1,645	139	2	1	3		15		Checks	S	Checks.
	78	94.2	22.8	7.0	25	0	1	3,150	2,900	671	128					2	4		T	Irregular grain.
	79	72.1	21.1	15.0	17	0	2	2,940	2,550	947	121				1	3	3		C. T	None.
	80	64.8	20.7	11.0	12	0	1	2,600	2,550	1,088	105	1	2	1	1	3	14		T	Large corner knot 48 inches from center.
Average		55.8	23.1	20.0	23			4,079	3,285	1,107	169									
2 by 8	81	41.7	24.8	35.0	39	0	1	6,530	4,100	1,364	222			3		10	2		C. T	Large corner knot 36 inches from center.
	82	32.6	25.4	18.3	42	0	2	5,840	4,450	1,557	198			10	1	10	2		C. T	Small corner knot at center.
	83	49.7	24.8	23.0	36	0	1	5,430	4,370	1,124	182					2	1		C. T	None.
	84	27.5	21.7	27.1	34	0	2	4,480	2,930	1,095	139			4	5	5	4		T. C	Bruise on lower face at center.
	85	117.3	23.6	34.4	50	0	2	4,380	3,360	1,345	147					3	2		C	Small corner knot 10 inches from center.
	86	123.0	23.5	28.0	11	0	2	4,290	3,270	1,133	135					11			C. T	None.
	87	41.9	18.4	16.0	28	0	1	3,860	2,740	718	129						2		C. T	None.
	88	79.0	19.9	5.5	9	0	2	3,710	2,260	1,090	124			5	1	1	7		C. T	None.
	89	58.1	31.2	26.0	23	0	1	3,560	3,060	1,172	120					7	1		T	None.

	90	63.8	18.0	20.0	11	0	2	3,520	2,880	751	113	...	...	...	...	1	...	...	T.	None.
	91	59.6	27.3	31.5	15	0	2	3,030	2,040	1,502	100	2	1	2	2	12	3	...	T.	Large corner knot 48i nches from center.
	92	70.6	16.8	7.0	8	0	1	2,700	2,280	971	87	...	1	...	1	...	1	...	C. T.	None.
	93	64.4	22.3	7.5	10	0	1	1,483	1,111	1,006	47	1	1	1	3	15	7	...	T.	Small corner knot 6 inches from center.
Average.	...	63.8	22.9	21.5	24	...	...	4,063	2,989	1,141	134	...	...	...	...	...	...	...	...	

TABLE 4.—*Results of individual tests on air-seasoned stringers and joists.*

Size.	Reference number.	Months seasoned.	Moisture.	Dry weight per cubic foot.	Rings per inch.	Sap.	Cross-section classification.	Modulus of rupture (per square inch).	Fiber stress at elastic limit (per square inch).	Modulus of elasticity (per square inch).	Horizontal shear (per square inch).	Knots. Vol. 1. Less than $1\frac{1}{2}$ inches.	Knots. Vol. 1. $1\frac{1}{2}$ inches and over.	Knots. Vol. 2. Less than $1\frac{1}{2}$ inches.	Knots. Vol. 2. $1\frac{1}{2}$ inches and over.	Knots. Vol. 3. Less than $1\frac{1}{2}$ inches.	Knots. Vol. 3. $1\frac{1}{2}$ inches and over.	Other defects.	Manner of failure.[1]	Apparent cause of failure.
Inches.			*Per ct.*	*Lbs.*	*No.*	*P.ct.*		*Lbs.*	*Lbs.*	*1,000 lbs.*	*Lbs.*									
8 by 16	1	24	56.3	23.3	20.8	0	1	6,320	...	...	423	...	...	...	...	...	...	...	C. T.	None.
	2	24	29.0	24.3	18.9	0	1	5,720	4,540	1,154	380	...	...	...	...	...	...	...	T. C.	None.
	3	42	16.8	23.2	17.1	0	3	4,930	3,240	1,347	321	1	...	3	1	11	5	...	T.	None.
	4	24	17.4	18.9	20.2	0	1	4,580	3,610	820	310	...	...	4	...	12	4	...	C. T. S.	None.
	5	42	16.7	17.4	21.2	0	1	2,870	...	...	191	...	...	...	2	2	5	...	T. S.	None.
	6	42	21.6	22.6	36.5	0	3	2,150	...	...	142	3	1	3	4	6	4	...	T.	Irregular grain caused by knot 56 inches from center.
Average.	...	...	26.3	21.6	22.4	...	...	4,428	3,797	1,107	294									
6 by 12	7	24	19.3	22.7	20.5	0	1	4,990	4,210	977	255	...	...	...	...	...	...	...	T.	None.
	8	42	15.2	25.0	23.6	0	1	3,820	3,180	527	191	...	...	...	...	...	...	...	T.	None.
	9	42	14.6	15.8	15.6	0	1	3,040	2,890	732	151	...	...	...	...	...	2	...	T.	None.
	10	24	15.7	21.1	14.2	0	1	2,980	...	...	147	...	...	...	...	3	3	...	T.	None.
	11	42	16.0	24.2	23.8	1	3	2,700	2,420	674	134	...	...	17	1	5	3	...	T.	None.
	12	24	15.8	19.5	8.4	0	1	2,590	...	...	125	2	2	1	2	5	...	...	T.	Small knot on lower face 31 inches from center.
Average.	...	...	16.1	21.4	17.7	...	...	3,353	3,175	728	167									
7 by 9	13	42	15.5	22.9	16.7	0	1	5,480	4,560	1,068	206	...	...	1	3	8	1	...	T. C.	None.
	14	42	15.3	26.8	17.7	0	1	4,590	...	...	184	...	...	...	...	...	...	...	S. T. C.	None.
	15	42	15.4	24.8	25.4	0	1	4,750	...	...	176	...	...	...	...	2	...	...	T.	None.
	16	24	15.8	17.3	6.1	0	1	3,320	...	...	121	...	...	...	...	...	...	...	T.	None.
	17	24	14.8	18.4	9.0	0	1	2,850	...	...	101	1	...	8	1	11	...	...	T.	None.
	18	24	18.6	21.4	16.4	0	1	2,660	2,000	1,140	96	...	1	1	2	9	6	...	T.	Irregular grain caused by knot 22 inches from center.
Average.	...	...	15.9	21.9	15.2	...	...	4,002	3,280	1,104	147									

[1] Letters indicate sequence and kind of failure; C. indicates compression, T. tension, and S. horizontal shear.

TABLE 4.—*Results of individual tests on air-seasoned stringers and joists*—Continued.

Size.	Reference number.	Months seasoned.	Moisture.	Dry weight per cubic foot.	Rings per inch.	Sap.	Cross-section classification.	Modulus of rupture (per square inch).	Fiber stress at elastic limit (per square inch).	Modulus of elasticity (per square inch).	Horizontal shear (per square inch).	Knots. Vol. 1. Less than 1½ inches.	Knots. Vol. 1. 1½ inches and over.	Knots. Vol. 2. Less than 1½ inches.	Knots. Vol. 2. 1½ inches and over.	Knots. Vol. 3. Less than 1½ inches.	Knots. Vol. 3. 1½ inches and over.	Other defects.	Manner of failure.[1]	Apparent cause of failure.
Inches.			*Per ct.*	*Lbs.*	*No.*	*P. ct.*		*Lbs.*	*Lbs.*	*1,000 lbs.*	*Lbs.*									
3 by 14	19	24	12.9	30.0	31.0	0	1	6,530			374			1					T	None.
	20	42	12.9	24.5	23.3	0	1	5,280			306	2		1		18			T	None.
	21	42	13.5	25.8	23.4	0	1	5,220			305					15	1	Checks	S. C. T.	None.
	22	24	13.1	22.3	16.9	0	1	4,520			261	1	1	1	1	5	8		T	Large corner knot 37 inches from center.
	23	24	13.7	26.2	24.9	0	1	4,370			252	1	1			9		Checks	S. T.	Checks.
	24	42	12.6	22.8	27.2	0	1	4,280			247		1	2	1	9	10		S	None.
Average			13.1	25.3	24.4			5,033			291									
2 by 12	25	23	15.5	32.8	14.0	0	1	7,230	4,810	1,303	359				1	4			T	None.
	26	24	12.5	20.7	15.7	0	1	5,320	3,340	1,272	254	1		2		11	7		T. C.	None.
	27	23	15.7	22.4	15.0	0	1	5,050	4,150	1,504	246			2		3	2		T	None.
	28	24	13.1	22.5	10.2	0	1	4,590			224					2			T	None.
	29	24	12.2	19.8	17.2	0	2	4,490	3,410	918	217			1			1		T	None.
Average			13.8	23.6	14.4			5,336	3,928	1,249	260									
2 by 10	30	24	12.6	25.9	24.5	0	2	6,140			247								T	None.
	31	24	12.3	20.6	8.5	0	2	5,000	3,110	1,245	200			6		14	3		T	None.
	32	23	16.1	24.7	50.0	0	1	4,840	4,690	1,651	194			1		8	2		S	None.
	33	23	15.7	24.0	24.0	0	1	3,950	3,470	698	162								T	None.
	34	24	12.4	21.0	17.0	0	2	3,100			126			6		3	2		S. C. T.	None.
Average			13.8	23.2	24.8			4,606	3,757	1,198	186									
2 by 8	35	24	12.4	25.3	24.2	0	2	6,680	5,070	1,737	219			3	1	3			T. S.	None.
	36	24	12.4	22.7	8.1	0	2	5,950	4,210	1,189	192			1		1			T	None.
	37	23	15.0	21.4	17.0	0	2	5,080	3,570	1,292	172	1				3	2		T	Irregular grain caused by knots.
	38	23	15.0	25.9	32.0	0	1	4,900	4,340	963	163			2	1		1		T	None.
	39	23	15.3	24.4	28.0	0	2	4,800	4,380	1,385	157								T	None.
	40	24	12.0	22.2	15.0	0	2	2,890			94	2			3	6	5		T	Small knot on lower face 6 inches from center.
Average			13.7	23.6	20.7			5,050	4,314	1,313	166									

[1] Letters indicate sequence and kind of failure; C. indicates compression, T. tension, and S. horizontal shear.

TABLE 5.—*Ratio of strength values of green redwood to those of green Douglas fir, with material of equal sizes.*

Bending.					Compression parallel to grain.		Compression perpendicular to grain.		Shear.
Size.	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.	Shear.	Size.	Crushing stress at maximum load.	Size.	Crushing stress at elastic limit.	Shearing strength.
Inches.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Inches.*	*Per cent.*		*Per cent.*	*Per cent.*
8 x 16	0.94	0.75	0.67	0.90	6 x 6	1.11	Large.	0.83	0.97
2 x 12	.83	.71	.64	.73	2 x 2	.99	....	....	....
2 x 10	1.04	.87	.69	.89	....	....	....	....	....
2 x 8	.83	.76	.71	.78	....	....	....	....	....
2 x 2	.91	.84	.66	.74	....	....	....	....	....

MOISTURE DETERMINATIONS.

Sections approximately 1 inch thick were cut from all of the specimens as soon as possible after they were tested. The sections were weighed and then dried to constant weight at 100° C. The difference between the original weight and the dry weight, divided by the dry weight, gives the percentage of moisture in the specimen at the time of test. In the stringers and joists an additional 1-inch section was taken from each piece. The pieces were cut into a number of portions, and the moisture content of each portion was determined separately in order to obtain a record of the distribution of moisture throughout the cross section. The parts of the cross sections in which the moisture contents were separately determined are shown in figure 1.

MISCELLANEOUS OBSERVATIONS.

All specimens were weighed and measured at the time of test. The average number of rings per inch, measured along a radial line, was computed, and the proportions of summerwood and of sapwood were recorded, as percentages. After the tests the specimens were either photographed or sketched to show the manner of failure and the location and size of defects.

DETERMINATION OF SEASONING.

In order to determine the rate of seasoning and its effect on the strength of the timber, 30 per cent of the pieces of each size were set aside to air season. The distribution of moisture in both green and air-seasoned material is indicated in figure 1. The quantities given in the diagram indicate the average moisture content as a percentage of the dry weight of the wood. On the pieces set aside for air seasoning, observations were made from time to time to determine their losses in weight and amounts of their shrinkage. The average results of these observations are shown in figure 2. In this diagram

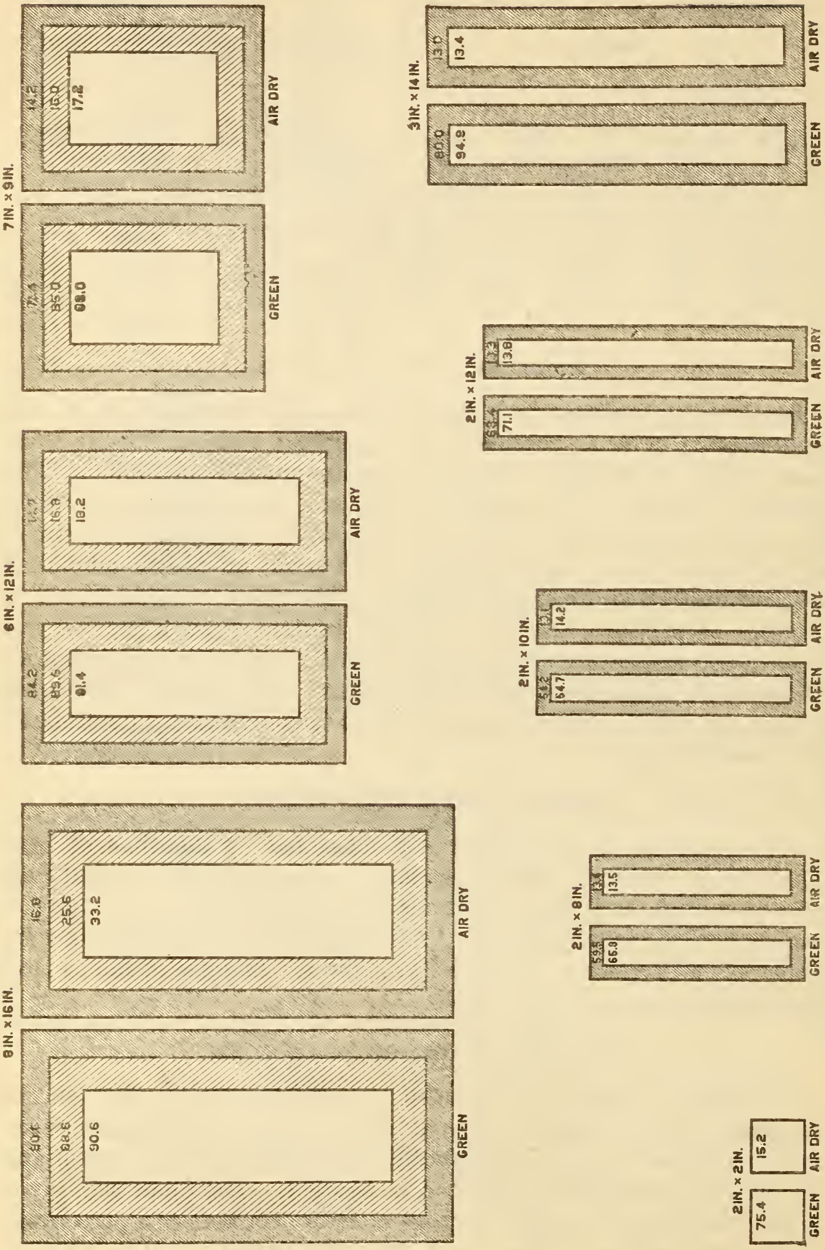

Fig. 1.—Average moisture distribution as determined by disks cut from green and air-seasoned specimens.

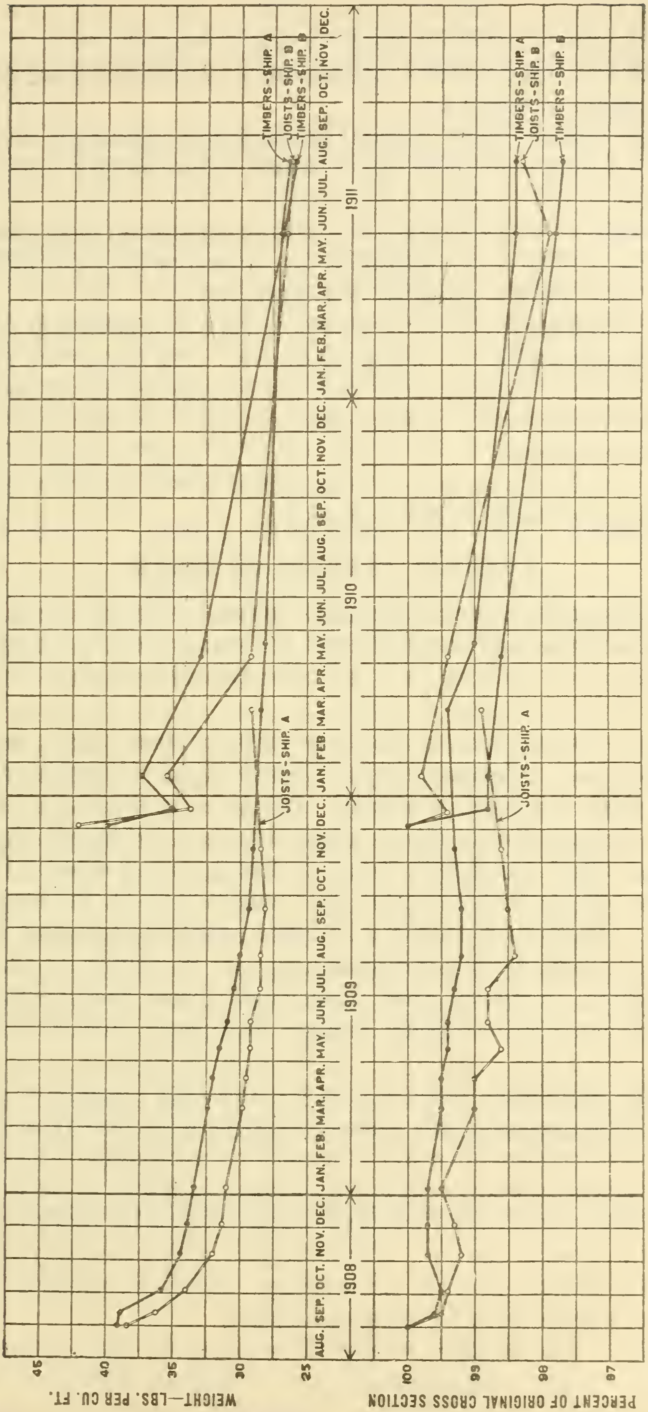

FIG. 2.—Loss in weight per cubic foot, and proportion of shrinkage in cross section due to seasoning.

the word "timbers" designates 8 by 16 inch, 6 by 12 inch, and 7 by 9 inch cross sections, and the word "joists" includes the four smaller sizes. The following general conclusions as to redwood are based on the data shown in figure 2:

1. Large timbers must season through two summers and joists through one summer before they reach a thoroughly air-seasoned condition.

2. Climatic conditions cause alternate evaporation and absorption of moisture. This is accompanied by corresponding shrinking and swelling of the surface portions of the timber.

3. The shrinkage factor for redwood is very low, although the wood contains a large amount of water when cut. The maximum moisture content was over 200 per cent and the average of the green pieces was about 75 per cent. During seasoning the average was reduced to about 16 per cent.

4. The low-shrinkage factor is an index of the fact that redwood can be seasoned easily without checking.

AVERAGE RESULTS OF TESTS.

Table 1 gives the average strength values for various sizes of both green and air-seasoned material, and the ratio of the strength values for air-seasoned material to the corresponding values for green material.

Small specimens, such as the 2 by 2 inch clear pieces, and even joists which are comparatively clear, show higher strength values for seasoned than for green material. In pieces larger than joist size, however, the increase in the strength due to seasoning is frequently more than offset by defects formed during the process. In other words, the strength of the piece as a whole may be decreased with seasoning. Because of this fact it is not advisable to count upon an increase in strength, due to seasoning, in the large pieces. It is safe to assume, however, that when large pieces are seasoned with reasonable care the working stresses for green material may be applied.

It will be seen from Table 1 that the shearing stresses which were actually developed in small, clear specimens are more than twice as high as the calculated shearing stresses for the bending tests. In the beam the actual area in resistance to shear is likely to be much less than that assumed in the formula because of checks, shakes, or other defects of a similar nature. The stringers which actually failed by longitudinal shear showed an average shearing strength of 302 pounds per square inch for green material.

In Table 2 the strength values of material of various sizes from Mendocino County (Shipment A) are compared with the strength values of similar material from Humboldt County (Shipment B).

The variation in strength between material from the two localities is no greater than can reasonably be expected between the individual pieces from one locality. The further analyses are therefore not kept separate.

Tables 3 and 4 give the results of individual tests, and from these results the tables for the principal bending tests were compiled. These can be used for the compilation of supplementary information.

Table 5 compares the strength of redwood and Douglas fir, as shown by Forest Service tests. In bending and compression at right angles to the grain redwood is about four-fifths as strong as Douglas fir, while in shearing strength and compression parallel to the grain for small, clear specimens the two species are practically equal. A large number of compression tests made by the University of California on specimens 4 inches square and 16 inches long gave an average value in compression parallel to the grain about 10 per cent greater for redwood than for Douglas fir.[1]

STRENGTH VALUES OF BEAMS AND SMALL PIECES.

In figure 3 the strength values, dry weight, and rate of growth are plotted for the individual beams of each size. The diagram was made by first plotting the solid line A, in which the values for modulus of rupture are arranged in order from the highest to the lowest. The other values (fiber stress at elastic limit, modulus of elasticity, dry weight per cubic foot, and rings per inch) were then plotted for each beam on the same vertical line as the modulus of rupture. The dotted lines indicate the average modulus of rupture and average crushing strength at maximum load of small clear specimens in comparison with the main test piece from which they were taken. It will be noted from this diagram that fiber stress at elastic limit, for the large bending specimens, and the crushing strength at maximum load, for the small specimens cut from them, bear a very close relation. This indicates that fiber stress at elastic limit is a measure of the quality of the wood fiber. The modulus of rupture, however, is influenced by all serious defects and is a measure of the quality of the beam as a whole. The more numerous and the more serious the defects, the closer the modulus of rupture approaches fiber stress at elastic limit.

[1] For comparison with other species see Bulletin 108, Tests of Structural Timbers.

TABLE 6.—*Variation of individual tests from the average; green material.*

Kind of test	Bending.									Compression parallel to grain.	Compression perpendicular to grain.	Shearing.
Kind of specimen	Stringers.			Joists.			Small, clear.			Small, clear.	Small, clear.	Small, clear.
Size of specimen	8 by 16 inches, 6 by 12 inches, and 7 by 9 inches, all 16 feet long.			3 by 14 inches, 2 by 12 inches, 2 by 10 inches, and 2 by 8 inches, all 16 feet long.			2 by 2 by 30 inches.			2 by 2 by 8 inches.	Stress area, 2 by 2 inches.	Shear area, 2 by 2 inches.
Strength factors	Modulus of rupture.	Fiber stress at elastic limit.	Modulus of elasticity.	Modulus of rupture.	Fiber stress at elastic limit.	Modulus of elasticity.	Modulus of rupture.	Fiber stress at elastic limit.	Modulus of elasticity.	Maximum crushing strength.	Crushing strength at elastic limit.	Shearing strength.
Number of tests	42	42	42	51	51	51	157	157	157	145	186	140
Average value, pounds per square inch	4,741	3,978	1,113,000	4,701	3,203	1,062,000	6,980	4,750	1,061,000	3,954	569	741
Per cent of total number of tests that fell above the average	41	45	54	38	43	47	45	46	52	44	38	50
Per cent of total number of tests that fell below the average	59	55	46	62	57	53	55	54	48	56	62	50
Distribution of individual tests with regard to the average, in per cent of total number of tests:												
Between 200 and 205 per cent of the average												
Between 195 and 200 per cent of the average												
Between 190 and 195 per cent of the average	1		1								1	
Between 185 and 190 per cent of the average												
Between 180 and 185 per cent of the average									1			
Between 175 and 180 per cent of the average											1	
Between 170 and 175 per cent of the average	1		1									
Between 165 and 170 per cent of the average											1	
Between 160 and 165 per cent of the average					2		1		1	1		
Between 155 and 160 per cent of the average	1	1		3				1			1	
Between 150 and 155 per cent of the average			1	1	2	3			1			1
Between 145 and 150 per cent of the average	4			2		3			2	1	1	
Between 140 and 145 per cent of the average	3	2	2	5	2	2	2	1	1		1	1
Between 135 and 140 per cent of the average	1	3	1	2	6	2	2	1	2	2	2	
Between 130 and 135 per cent of the average	1	2	1	2	2	2	3	3	4	2	1	2
Between 125 and 130 per cent of the average	4	2	2	3	3	3	2	5	4	2	3	1

Between 120 and 125 per cent of the average......	5	6	11	1	3	5	6	3	7	6	4	5
Between 115 and 120 per cent of the average......	5	6	13	1	4	2	3	7	6	6	2	5
Between 110 and 115 per cent of the average......	3	6	4	5	8	3	6	8	7	6	5	8
Between 105 and 110 per cent of the average......	4	10	6	7	2	8	11	7	6	6	7	13
Between 100 and 105 per cent of the average....	8	7	11	6	9	9	9	10	10	12	8	14
Between 95 and 100 per cent of the average.......	14	6	10	13	7	7	9	11	7	14	12	16
Between 90 and 95 per cent of the average........	9	10	4	13	20	16	13	11	7	11	12	12
Between 85 and 90 per cent of the average........	8	17	4	8	4	4	7	12	7	13	10	9
Between 80 and 85 per cent of the average........	5	6	6	9	3	4	13	7	3	6	6	4
Between 75 and 80 per cent of the average........	8	4	4	7	9	3	9	5	4	5	8	2
Between 70 and 75 per cent of the average........	4	4	1	4	7	2	3	4	5	4	5	2
Between 65 and 70 per cent of the average........	1	7	5	3	3	8	....	3	5	3	4	2
Between 60 and 65 per cent of the average........	4	....	6	2	2	6	1	....	4		2	2
Between 55 and 60 per cent of the average........	4	1	4	2	1	3	....	1	4	....	3	1
Between 50 and 55 per cent of the average........	....		2				....	....	1	....		
Between 45 and 50 per cent of the average........	2	....	....	....	....	....	....	....	1	....	....	
Between 40 and 45 per cent of the average........	....	....	....	1	1	....	....	....		....	....	....
Between 35 and 40 per cent of the average........	....	....	....	....	....	....	....	....	....	....	....	....

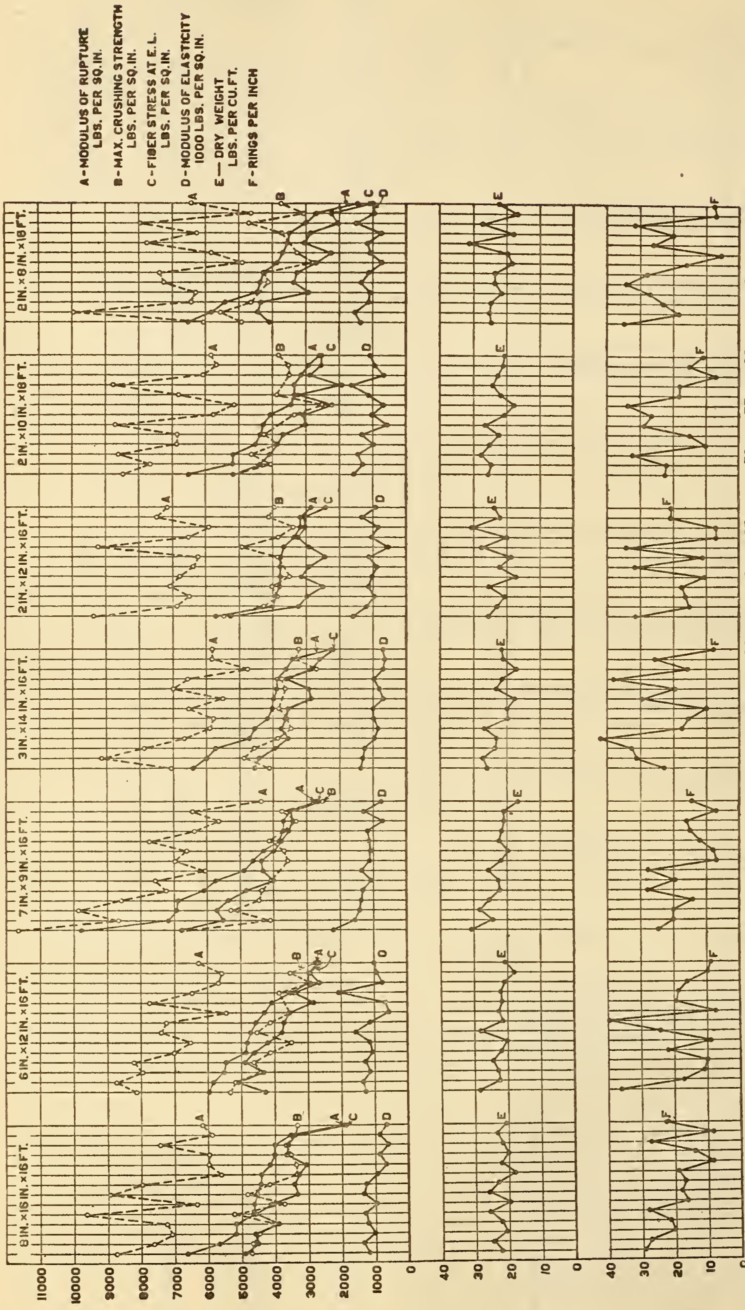

FIG. 3.—Strength values, dry weight per cubic foot, and rings per inch of green stringers and joists, and strength values of minor specimens cut from them.

VARIATION OF INDIVIDUAL RESULTS.

Average results in a material as nonhomogeneous as timber are of general significance only; unless the relation of the individual results to the averages is available, the averages may create an entirely erroneous impression.

Table 6 shows how the individual tests of the different classes vary from the averages given in Table 1.

The upper part of the table gives general data on the different classes of tests, while the lower part shows the distribution of the individual tests of each class above and below the average, which is indicated by the heavy line.

The proportion of the total number of tests which fell within certain limits indicated by the scale at the left of the table is shown by the figures in the columns. For example, under "Modulus of rupture for stringers," 5 per cent of the total number of stringers fell between 115 and 120 per cent of the average value, and only 1 per cent between 180 and 205 per cent of the average. In general, with a greater number of tests, there will be a more uniform distribution above and below the average, a larger proportion near the average, and a more uniform diminution with the distance from the average. Without doubt, all the values shown in this table would be changed to some extent by additional tests, and the distribution indicated will assist the reader in judging whether the average value would be increased or decreased by a larger number of tests.

RELATION OF MECHANICAL TO PHYSICAL PROPERTIES.

Wood differs from concrete, steel, and other construction materials in that its structure is so variable. For this reason it is necessary, in the inspection of structural timber, to understand what certain physical properties indicate, so that weak timber may be excluded. The physical characteristics of redwood timber which can be readily determined are: Color of the wood; relative proportion of heartwood and sapwood; position of the pith in cross section; rate of growth as shown by size of rings; weight; and proportion of summerwood.

COLOR.

The color of the heartwood, varying in redwood from light cherry to dark mahogany, is produced by deposits of various materials resulting from the process of growth. The sapwood is free from these materials and is almost white. Ordinary variations in the color of the heartwood apparently do not affect the mechanical properties of the wood. However, the appearance of pockets of punky, almost black, wood at the base of the trunk indicates a form of decay called brown, butt, or pin rot. It starts in the inner rings of the heartwood and extends outward to the sap and sometimes into the sap. As a rule it does not extend upward over 10 or 15 feet.

PROPORTION OF HEARTWOOD AND SAPWOOD.

In lumbering redwood it is customary to remove the thick bark from the logs before hauling them to the mill. After being allowed to dry, this bark is burned as it lies by the logs, together with the brush and limbs. At the same time most of the sapwood is destroyed, so there is very little sapwood in market material.

POSITION OF PITH.

In many specifications for large timbers the position of the pith or heart of the tree is considered, and the term "boxheart" is used to indicate those having the heart within the beam. Figure 4 shows the method of classification adopted by the Forest Service to indicate the position of the pith. In general, this factor is significant

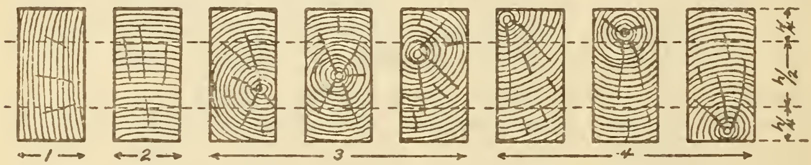

FIG. 4.—Classification of cross sections of test specimens.

1. Pith not in cross section. Rings vertical.
2. Pith not in cross section. Rings horizontal.
3. Pith within center half of cross section.
4. Pith within upper or lower quarter of cross section.

because of its relation to seasoning checks, which extend from the surface toward the pith. In class 3 the likelihood that checks will cause failures by horizontal shear is much greater than in any of the other positions of the pith. In redwood, however, the trees are so large that this class is not at all common; season checks are not numerous, and the relative position of the pith has little significance.

RATE OF GROWTH.

The rate of growth is determined by counting the annual rings intersecting a radial line of the cross section and dividing the number of rings by the length of the line in inches. Figure 5 shows the relation of rate of growth to modulus of rupture, to fiber stress at elastic limit, and to modulus of elasticity in small, green beams free from defects. It shows also the crushing strength at maximum load in compression parallel to the grain in small specimens cut from these beams. It appears from this diagram that the strongest wood is associated with a growth rate of about 30 rings per inch.

The individual points plotted for this diagram have a wide variation, and too much importance should not be attached to the relations shown, especially in commercial timbers containing defects. Figure 3 shows that there is no definite relation between strength

and rate of growth for large pieces with ordinary defects. Otherwise the curves showing rate of growth would bear a definite relation to the strength curves.

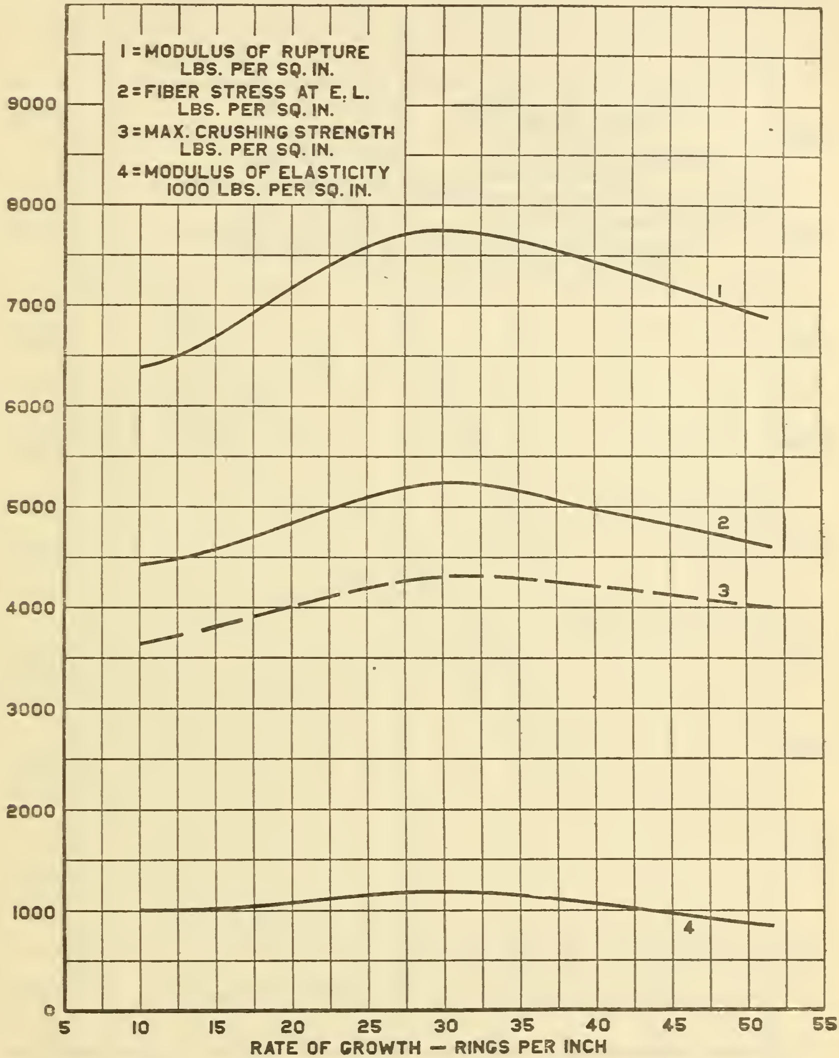

FIG. 5.—Relation of strength in bending and compression parallel to grain to rate of growth, as shown by the number of rings per inch; small, clear, green specimens.

WEIGHT.

Figure 6 shows the relation between the dry weight per cubic foot and the modulus of rupture, the fiber stress at elastic limit, and the modulus of elasticity for small, clear, green beams. It shows also the crushing strength at maximum load in compression parallel to

the grain in small specimens cut from them. This diagram confirms for redwood the conclusion which has been brought out for other species, that the mechanical properties of the clear wood vary directly with its dry weight. Reference to figure 3 shows how

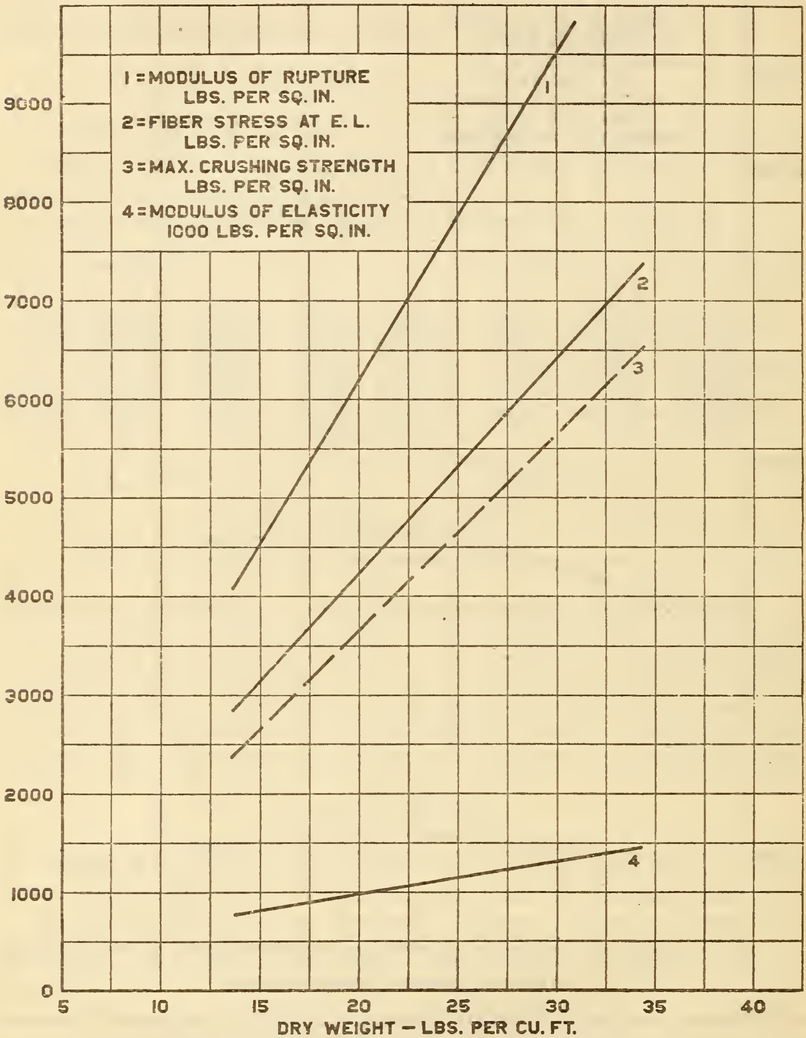

FIG. 6.—Relation of strength in bending and compression parallel to grain to dry weight per cubic foot; small, clear, green specimens.

this relation holds, and indicates a sharp drop in the modulus of rupture as the weight decreases. In structural timbers containing defects the relation between weight and strength will of course be influenced by the position and size of the defects.

PROPORTION OF SUMMERWOOD.

Summerwood is the term used to denote the dark, relatively dense portion of each annual ring. The light, porous portion is

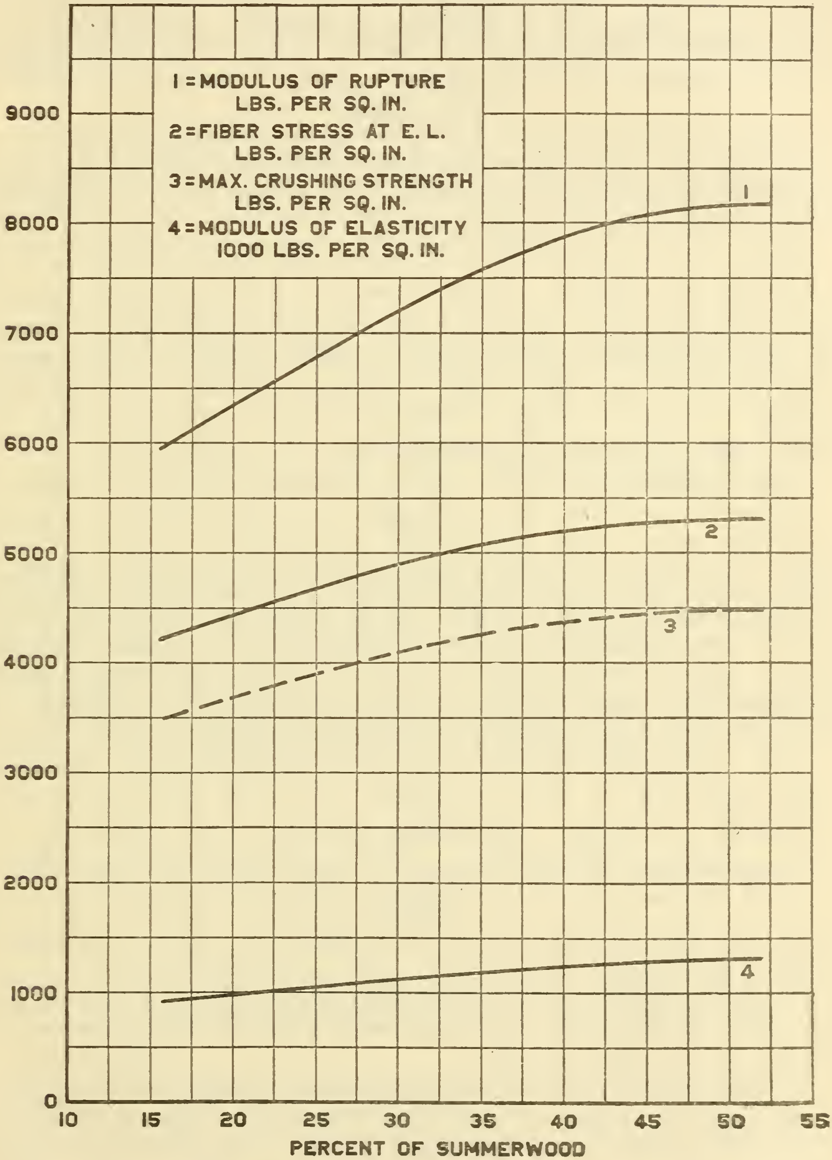

FIG. 7.—Relation of strength in bending and compression parallel to grain to per cent of summerwood; small, clear, green specimens.

termed "springwood." Summerwood is expressed as a percentage of the area of the cross section. Figure 7 shows the relation between the proportion of summerwood and the strength values in small,

clear, green specimens, tested in bending and compression parallel to the grain. In large pieces the proportion of summerwood is likely to vary, and the strength is so apt to be influenced by knots and other defects that in many timbers the proportion of summerwood is of little value in judging the strength. Nevertheless, the proportion of summerwood, independent of knots and other defects, is an important guide in judging the quality of redwood timbers.

FAILURES.

The failures of the redwood stringers and joists indicate the probable behavior of similar material. The results of the individual tests are contained in Tables 3 and 4.

These tests show, in the first place, that in all stringers, both green and air-seasoned, the proportion of first failures by horizontal shear was very low, since only 5 per cent of the green and 6 per cent of the air-seasoned pieces failed in this manner. In the green material 55 per cent failed first by compression and 40 per cent by tension. In the air-seasoned material 83 per cent failed first by tension and 11 per cent by compression.

In the stringers which failed first by tension, both green and air-seasoned, the greatest loss in strength is due apparently to irregular and cross grain. Such defects may or may not be associated with knots. The green stringers which failed by tension due to irregular or cross grain were only 63 per cent as strong as the average for all green stringers tested; the air-seasoned stringers so failing were only 51 per cent as strong as this average. The average strength of all stringers which failed first by tension was about three-quarters as great as the average strength of all green stringers.

As far as could be observed, only 13 per cent of the green stringers which failed first by compression, and none of the air-seasoned, were influenced by defects. The average strength of the green and air-seasoned stringers which failed first by compression was, respectively, 118 and 115 per cent of the average for all green stringers, and even those in which defects apparently influenced the failure were slightly above this average.

The few stringers which failed first by horizontal shear show a strength both for green and dry material practically the same as the average for all green stringers.

An examination of the calculated shearing strength in the stringers shows that in all cases, whether shear was the first failure or followed some other failure, or was not developed, the average calculated shear was higher in the green than in the dry specimens.

GRADING.

Because of the amount of clear material which may be had and the localized area of consumption, it has not been necessary to have the grading rules for redwood as specific as they are for some other species.

However, as redwood becomes better known, and as a wider distribution is secured, stricter rules for classifying the material will be necessary.

REDWOOD LUMBER MANUFACTURERS' RULES.

The grades in use by the redwood lumber manufacturers are as follows:

CLEAR REDWOOD.

Shall be good and sound, well manufactured, free from knots, shakes or splits, with the exception of season checks not to exceed 4 inches in length; will allow reasonable amount of birdseye and a fair proportion in each shipment may contain pin knots and small sound knots showing on one face only, and sap not exceeding 4 per cent of areas of all the surfaces, and slight variation in manufacture.

SURFACED CLEAR.

Shall be well manufactured and worked smoothly to uniform thickness. Will admit of slight roughness or variation in milling and defects mentioned under grade of clear.

SAP CLEAR.

Shall conform generally to the grade of clear, except that it may contain sap in excess of 4 per cent of the area of the surfaces. Will allow discoloration of sap.

COMMON.

Number 1 shall consist of lengths 10 feet and longer (except where otherwise specified) of sound lumber and free from such shakes, large or loose knots, or other defects that would materially impair its usefulness. Will allow slight variation in width and thickness. Sap not to exceed 4 per cent of the area of all the surfaces.

Number 2 shall consist of lengths 10 feet and longer (except where otherwise specified) free from splits extending more than one-sixth of its length. Will allow knots (sound or unsound), sap, shakes, and other defects which render it unfit for good, substantial construction purposes, but suitable for an inferior class of work.

STRIPS.

1 x 3, 4, and 6 inches.

Shall conform to above rules except that lengths shall be 10 feet and longer.

BOARDS.

Number 1 (8 inches and wider) shall be well sawed, 10 feet and longer, free from shakes and splits, admitting any number of sound knots less than 2½ inches in diameter and one knot, black or red, 2½ inches in diameter in each 5 superficial feet. Will allow slight variation in width and thickness. Sap not to exceed 4 per cent of the area of all surfaces.

Number 2. Will allow sap, loose and rotten knots, shakes, and other recognized defects which render it unfit for good, substantial construction purposes, but suitable for an inferior class of work. Also splits not extending over one-fourth the length of the piece.

STANDARD GRADE, RUSTIC STOCK.

Will allow three or four sound knots 1¼ inches in diameter. One or two sound knots between 1¼ and 2 inches in diameter. Sap with small knots. Poor machining, which would make it unfit for Clear.

Grain of all grades shall be as the lumber runs.

TENTATIVE GRADING RULES.

In Bulletin 108 of the Forest Service [1] a set of tentative grading rules for structural timbers is presented. It is the purpose of these rules to divide structural timbers, on a basis of the appearance of the individual pieces, into the following grades:

Grade 1.—Timbers having a modulus of rupture over 4,000 pounds per square inch.

Grade 2.—Serviceable timbers having a modulus of rupture under 4,000 pounds per square inch.

Culls.—Timbers having visible defects which render them unfit for structural purposes.

Application of these rules to redwood and eight other species gave a good strength classification in every case. It should be understood that these tentative rules are for the purpose of strength classification only and do not take into account requirements of a general nature such as conformity to dimensions, proportion of sap, or any other requirements which might be made necessary by peculiarities of certain species.

DEFINITIONS.

In the tentative rules which have been advanced a number of new definitions have been put forward.

Dense wood.—The term "dense wood" will be used to define the quality of wood which is desired in timbers subjected to stresses such as occur in frame structures. The term applies to the wood itself, irrespective of defects. Since dry weight, which is the most accurate index to the mechanical properties of wood, can not be determined from a casual inspection of the timber, dense, or, in other words, comparatively heavy wood will be defined as:

1. Wood that shows more than eight rings per inch, or which contains rings with more than 30 per cent summerwood.

2. Wood which is resilient; that is, wood which when struck with a hammer, or similar blunt instrument, gives a sharp, clear sound, while the hammer shows a marked tendency to rebound, and the wood a tendency to recover from the effects of the blow.

These properties are to be judged from an inspection of the cross section of the timber.

Knots.—Knots are portions of branches which have been encased in the growing trunk of the tree. In judging their effect upon the strength of timber it should be borne in mind that the axis of a knot always extends to the center or pith of the tree,[2] and that the visible part of the knot is a section of a somewhat conical mass of wood, the apex of the cone being at the pith of the tree, and the knot, as a whole,

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[1] Tests of Structural Timbers, by McGarvey Cline and A. L. Heim.

[2] Exceptions to this rule are found where knots are caused by adventitious branches, but such exceptions are so rare that they can be ignored in the grading of structural timbers.

more or less intertwined with the wood surrounding it. A spike knot is a longitudinal section of a whole knot, and a round or elliptical knot is a section, respectively at right angles or at some oblique angle, to the axis of the knot. Sound knots, as a rule, are stronger and harder than the wood fiber surrounding them. Their effect, therefore, upon the strength of the timber depends to a large extent upon the manner in which they are connected to the surrounding wood and upon the degree of stress to which the connecting fibers are subjected. If the knots disturb the grain so that it is decidedly oblique to the edges of the timber, the wood will be subjected to stresses in tension at right angles to the grain, the kind to which it offers the least resistance. In such cases early failure in cross-grain tension almost invariably results.

Class 1 knots: Class 1 knots must be solid, firmly attached to the surrounding wood, and must cause no marked irregularity in the grain of the timber. Small spike knots will be included in this class.

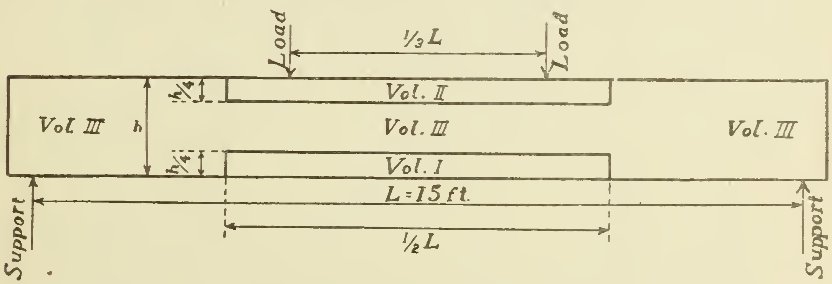

FIG. 8.—Diagram to show method of locating defects in stringers.

Class 2 knots: Class 2 knots must be solid, but are insecurely attached to the surrounding wood, or associated with burl or other irregularity in the grain.

Class 3 knots: Class 3 knots are unsound knots; that is, they are softer than the surrounding wood.

Dimensions of knots: The dimension of a knot on the narrow face of a timber will be the projection of the knot on a line perpendicular to an edge of the timber. On the wide, or vertical, faces the smallest diameter of a knot is to be taken as its dimension.

Small knots: Knots less than $1\frac{1}{2}$ inches in diameter.

Large knots: Knots $1\frac{1}{2}$ inches or more in diameter.

Position of defects.—The position of defects is designated by means of the three volumes indicated in figure 8.

TENTATIVE RULES FOR REDWOOD.

Grade 1 timbers.

(*a*) Must contain only dense wood.

(*b*) Must not have class 2 or large class 1 knots in volume 1.

(*c*) Must not have large class 2 knots in volume 2.

(*d*) The aggregate diameters of knots on any face within the center half of the length shall not exceed the width of the face.

(*e*) Must not have shakes or deep checks.

(*f*) Must not have diagonal grain with a slope greater than 1 inch in 20.

Grade 2 timbers.

(*a*) Must contain only dense wood.

(*b*) Must not have large class 2 knots in volume 1.

(*c*) The aggregate diameters of knots on any face in the center half of the length shall not exceed two times the width of the face.

(*d*) Must not have shakes which extend along an annual ring a distance greater than the width of the piece.

COMPARISON OF GRADING RULES.

Table 7 shows the results of applying the two grading rules to the 42 green redwood stringers tested. The lumber manufacturers' rules were applied to the pieces in accordance with their appearance before testing. The proposed tentative grading rules were applied through photographs and sketches of the pieces, which showed the size and location of defects. There was no opportunity in the latter case, therefore, to judge the resiliency of the timber, and only the defects were considered. Comparison of the results obtained from the two sets of specifications indicates that the tentative rules permit a larger proportion of material in the highest grade than the manufacturers' rules do; that the range in strength values for first-grade material is the same for both classifications; and that with the proposed rules those pieces ordinarily graded common, and which showed high strength values in test, fall in the best grade.

TABLE 7.—*Comparison of manufacturers' grading rules with the tentative rules.*

Grades.	No. of tests.	Modulus of rupture.	Fiber stress at elastic limit.	Modulus of elasticity.
		Pounds per square inch.	*Pounds per square inch.*	*1,000 pounds per square inch.*
All grades:				
Average	42	4,741	3,978	1,113
Maximum		9,760	6,750	2,222
Minimum		1,930	1,880	566
Lumber manufacturers' rules:				
Clear—				
Average	11	5,431	4,446	1,169
Maximum		9,760	6,750	2,222
Minimum		4,000	2,840	607
Common—				
Average	31	4,496	3,811	1,093
Maximum		7,180	5,530	1,572
Minimum		1,930	1,880	566
Proposed grading rules:				
Grade I—				
Average	29	5,088	4,202	1,163
Maximum		9,760	6,750	2,222
Minimum		4,000	2,840	566
Grade II—				
Average	13	3,469	3,157	928
Maximum		5,750	4,000	1,290
Minimum		1,930	1,880	645